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Using Repeat Landscape Photography to Assess Vegetation Changes in Rural Communities of the Southern Appalachian Mountains in Virginia, USA

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Repeat photography is a useful tool for evaluating historical landscape change. The objective of this study was to use ground-based repeat photography to quantify landscape vegetation changes during the period of 1880–2008 and to evaluate methods employed in repeat photography. The historical photographs included 237 landscape photographs taken in 1880 in the southern Appalachian Mountains. Fifty-five photographs were successfully relocated, and the photograph pairs were analyzed for changes in cover classes and changes by topographical position. From 1880 to 2008, forest land was the most stable cover type (98% of forested land in 1880 remained forested in 2008). Some of the main patterns of land conversion during this time period were (1) agricultural land converted to forest (19%), (2) residential and commercial land converted to forest (18%), and (3) transportation systems converted to forest or agricultural land (57%). When combined with other historical land use methods, repeat photography can yield a detailed reconstruction of the historical profile of an area; however, if the original locations of the photographs are unknown, repeat photography is a very time-intensive technique.

Keywords: *Land use history; repeat photography; early European settlement; vegetation change; Appalachian Mountains; Virginia; USA.*

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Introduction

Repeat ground-based photography enables the comparison and interpretation of changes between historical and current landscape patterns. The paired historical and modern photographs demonstrate how vegetation and human land use have changed over time and create a historical profile of the landscape to predict how similar areas may respond to future changes (Vale 1987; Butler and DeChano 2001; Pickard 2002; Moseley 2006). Repeat photography has also been used to quantify vegetation shifts caused by climate change and reconstruct trends in landscape vegetation change, such as tree encroachment, land conversion, field abandonment, or forest fragmentation (Veblen and Lorenz 1988; Skovlin et al 2001; Skirvin et al 2008). Evaluating landscape change through repeat photography is useful because it can provide spatially and temporally specific information about succession and human land use trends (Moseley 2006).

Assessing human impacts on the environment is well suited to repeat photography (Zier and Baker 2006), and it is particularly useful in rural communities that lack other sources of historical vegetation data. In Arizona, human clearance of trees for fuel and fencing was clearly visible in repeat aerial photography (Hutchinson et al 2000), and in the Colorado Front Range, logging, burning, grazing, recreation, and residential development were all detected with repeat photography (Veblen and Lorenz 1991). In China, forest policies have been changed because of the information obtained from repeat photography (Moseley 2006), and in other regions, repeat photography is being used to assess short-term changes in rapidly progressing environmental safety concerns (Marck et al 2006).

The objectives of this study were to (1) quantify and identify landscape vegetation changes during the period 1880 to 2008 from repeat photographs and (2) to identify characteristics that make a photograph collection suitable for a repeat photography study. We opted to work with this particular set of photographs because the collection was unique in terms of size (237 photographs) and composition (many landscape photographs) and because it originates from a region of the country that lacks extensive historical written documents as a result of damage to records during the American Civil War. The original photographs were taken shortly after the American Civil War and represent a period of peak agricultural activity. The current photographs represent a time when large expanses of agricultural land were abandoned (Eller 1982).

Methods

Data description

The historical photographic set included 237 photographs taken by J.C. Porter and stored in Virginia

Polytechnic Institute and State University's Special Collections Archive. The documentation with the photographs only states that the collection was donated by a retired wetlands professor, but does not provide any information about the photographer other than his name and the date and approximate location where each photograph was taken. Although little is known about Porter, the collection is unique because many photographs show landscapes, creeks, and agricultural scenes. The photographs were taken during the winter in the 1880s when the deciduous trees were leafless, which made the ridgeline outlines very distinct and easy to see.

Photographs from this data set were separated into 2 categories: unsuitable for repeat photography and potentially suitable. Photographs were classified as unsuitable if: (1) they lacked sufficient topographical features for relocation, (2) vegetation in the foreground was too dense, (3) a building occupied most of the photograph, or (4) the photograph was a double exposure. Photographs classified as potentially suitable typically had a distinctive ridgeline with a fairly broad field of view.

Study area description

The photographs were all taken in Virginia's Ridge and Valley physiographical province and cover an area from Newcastle (37.5°N; 81.1°W) south to Saltville (36.8°N; 81.7°W). The topography consists of long, narrow parallel ridges and valleys (Creggar and Hudson 1985). Sandstone dominates the ridge tops, and limestone is in the valleys. Elevations are 457–1371 m asl. The average winter temperature is 2°C, and the average summer temperature is 26°C. The mean annual precipitation is 990 mm. Dominant deciduous species are *Acer rubrum*, *Carya* spp, *Liriodendron tulipifera*, *Pinus rigida*, *P. virginiana*, *Quercus alba*, *Q. velutina*, *Q. coccinea*, *Q. prinus*, and *Q. rubra* (Braun 1950).

European settlers entered this area around 1654 (Johnston 1906). By the late 1800s, much of the forest was cleared for agriculture, timber, and mining for coal, salt, and gypsum. Typical agricultural operations included grazing livestock, grain production, and burley tobacco. Europeans settled first in the valleys, and, as this space was occupied, later settlers established homes in the hollows and ridges. Many private landholders experienced economic hardship during and after the Civil War, which resulted in land abandonment. In 1936, the Jefferson National Forest was created to conserve and manage the forest resources in this region. However, agriculture, timber extraction, and mining remained important on privately owned land.

Repeat photography methods and analysis

The current photographs were taken in the winters of 2007 and 2008. Brief descriptions included in the Porter photograph collection were used to identify the photograph locations. Most descriptions provided a town, county, or creek, and occasionally a distance from a mill or town. The most efficient way to relocate a photograph site was to interview local residents. In some instances, current landowners owned additional historical photographs from their property that, when used in conjunction with Porter's photographs, enabled us to relocate the original photograph location. If no local knowledge of the photographs was available, we attempted to match landscape features—a very time intensive process. When a photograph site was relocated, a global positioning system was used to record its location and a new photograph was taken that maintained the landscape features, camera angle, and field of view of the original photograph.

The paired historical and modern photographs were imported into Adobe Photo Elements, and the same image area was marked within each photograph using common landscape features to ensure comparison of the same land area. Each common image area was the same size and pixel resolution. Thus, comparisons between the 2 time periods could be done by directly comparing pixel counts. Within each photograph, the lasso tool in Elements was used to categorize each pixel as agriculture (AGR), distant mountain (DMT), forest (FOR), residential or commercial (RES), rock outcrops (ROC), sky (SKY), transportation systems (TRN), or water (WTR). Agriculture included pastures and cultivated fields. Distant mountains described areas on ridges where it was impossible to determine the vegetation or land use. Residential or commercial structures included houses, barns, buildings, and rock walls. Transportation systems included roads, bridges, railroad cars, railroad tracks, parking lots, and road equipment. The change in pixel count for each cover type was then used to quantify landscape and land use change.

Once the pixel count for all pairs was complete, we identified the topographical position for each category in both the 1880 photographs and the 2008 photographs. Topographical positions were classified as ridge, midslope, or valley. Percent change between the 2 time periods was computed, and a chi-squared contingency table analysis was used to test whether the proportion of pixels varied across topographical positions between the 2 time periods. We used a significance level of $P \leq 0.05$.

Results

Repeated photographic pairs

From the collection of 237 photographs in the Porter collection, 104 (44%) were categorized as unsuitable and 133 (56%) as potentially suitable. Of the 133 potentially suitable photographs, 74 photographs were relocated. To ensure quality in the comparisons, 19 of the 74 pairs were removed from further analysis because they lacked features that clearly enabled the same landscape section to be delineated. Thus, from the original collection of 237 photographs, 55 photographic pairs (23%) were used to assess trends in land use and vegetation change (Table 1).

Landscape vegetation change: 1880–2008

From 1880 to 2008, FOR was much more stable than AGR (Table 2). During the study period, 20% of AGR was converted to FOR (Figure 1). The trend of land conversion to FOR was a pattern also seen in other cover types, most notably ROC (54% converted to FOR), DMT (40%), RES (18%), and TRN (27%). In many cases, these conversions to FOR represent the growth of trees in the foreground of photographs, which obscured features that had been visible in the 1880 photographs. Although TRN represents a small portion of the overall landscape (4%), it experienced substantial transitions in both the creation of new transportation systems on lands formerly used for RES (11%) and the conversion of former transportation systems to AGR (30%) and FOR (27%). The former conversion was a result of widened roads and new bridges (Figure 2), and the latter was a result of a reduction in the area used for railroads (Figure 3). The decrease in SKY reflects tree growth and building construction. The conversion of WTR to AGR (13%) is due to a combination of river and stream channel shifts and the loss of mill ponds.

Photograph analysis results for topographical land use changes

From 1880 to 2008, 4 cover types varied significantly by topographical position (Table 3). Conversion patterns of FOR varied significantly across the 3 topographical positions, with ridges experiencing the least change in forest, midslopes a moderate amount of change, and valleys experiencing a substantial increase in forest cover. Changes in AGR also significantly varied by topographical position, and ridge sites experienced a 100% loss, midslope positions lost about one third, and valleys had only a slight reduction. Residential and transportation systems also significantly varied by topographical position, although neither was present at the ridge sites during either period.

Discussion

Repeat photography

Repeat photography has been employed in many different environments to quantify historical vegetation change (Hart and Laycock 1996; Griffin et al 2005; Moseley 2006). As the technique becomes more common, it is being used for environmental monitoring and policy creation (Marck et al 2006; Moseley 2006) and by necessity must become more quantitative, for example, the pixel-level analysis conducted by Crimmins and Crimmins (2008). However, we found a number of limitations with the technique that are important to consider when interpreting results from a repeat photography project. First, we found a strong spatial bias in our photographs, with most taken along roads or other transportation routes and many sets of “grouped photographs” where multiple images were taken from a single point. This spatial bias may be due to the size and weight of historical camera equipment, but steep and inaccessible areas were less commonly photographed and easily accessible locations were overrepresented compared to their proportional distribution on the landscape. Interestingly, a similar topographical bias has been found in metes-and-bounds witness tree data, where surveyors recorded fewer witness trees in inaccessible areas (Black and Abrams

TABLE 1 Percent change in pixels in each cover class in photographs taken in 1880 and 2008 in Virginia, USA. The total number of pixels is listed in parentheses following the percents. Cover classes are abbreviated as AGR (agriculture), DMT (distant mountain), FOR (forest), RES (residential or commercial), ROC (rock), SKY (sky), TRN (transportation system), and WTR (water).

Cover class	1880 photographs	2008 photographs
AGR	21.4% (3,180,190)	17.4% (2,592,473)
DMT	4.3% (645,906)	2.6% (388,731)
FOR	15.8% (2,359,179)	28.9% (4,294,172)
RES	12.1% (1,800,454)	10.0% (1,493,272)
ROC	0.4% (61,537)	0.2% (28,208)
SKY	34.5% (5,150,028)	31.6% (4,706,461)
TRN	4.2% (628,055)	3.7% (549,005)
WTR	7% (1,064,219)	5.6% (837,246)
Total pixels	14,889,568	14,889,568

TABLE 2 Percent change in cover classes between 1880 and 2008 from repeat photographs taken in Virginia, USA. The actual change in pixel number is listed in parentheses below the percent. The cover classes are abbreviated as AGR (agriculture), DMT (distant mountain), FOR (forest), RES (residential or commercial), ROC (rock), SKY (sky), TRN (transportation system), and WTR (water).

Cover class in 1880	Cover classes in 2008							
	AGR	DMT	FOR	RES	ROC	SKY	TRN	WTR
AGR	−31.3% (2,186,038)		+19.9% (633,906)	+6.2% (198,076)			+4.7% (148,800)	+0.4% (13,370)
DMT		−39.8% (388,731)	+39.8% (257,175)					
FOR	+0.8% (18,284)		−1.7% (2,319,497)	+0.8% (17,641)				+0.2% (3757)
RES	+3.9% (70,691)		+17.7% (319,507)	−34.9% (1,172,706)			+10.6% (191,023)	+2.6% (46,527)
ROC			+54.2% (33,329)		−54.2% (28,208)			
SKY			+8.4% (432,404)	+0.2 (11,163)		−8.6% (4,706,461)		
TRN	+28.9% (181,457)		+26.8% (168,296)	+14.0% (87,954)			−69.7% (190,348)	
WTR	+12.8% (136,003)		+12.2% (130,058)	+0.5% (5732)			+1.8% (18,834)	−27.0% (773,592)

2001). Second, many photographs lacked the landscape features necessary for relocation; in this study we were able to analyze only 55 out of the original 237 photographs. Repeat photography has been used more frequently in mountainous terrains, and we think this is because there is a higher probability of relocating photographs in areas with greater topographical relief (Skovlin et al 2001; Moseley 2006). A third difficulty was the problem of visibility (Nüsser 2001). In many instances new tree growth or buildings hid or obscured views, and shadows, clouds, fog, snow, or rain showers reduced the quality of the image. Revisiting sites solved weather difficulties, but we found no solution for new trees or buildings.

Landscape vegetation changes in the southern Appalachian Mountains

Repeat photography is best when used in combination with other historical techniques. Our photographs document a major shift in conversion of AGR to FOR, and this pattern is documented over a regional area (Table 2). When our regional data are combined with local dendrochronology studies (Ambers et al 2006; Copenheaver et al 2006) and local witness tree records covering the same time period (Flatley 2006), it is possible to identify a double phase of agricultural abandonment and subsequent forest establishment. The less fertile and more xeric fields on the ridge tops were abandoned in the 1880s when a major shift in land use and land ownership was triggered by the end of the American Civil War. A second phase of agricultural abandonment occurred at midslope sites in the 1930s during the Great Economic Depression. This later phase of land abandonment also included former forest land that had been cut for timber in the early 1900s (Copenheaver et al 2007).

Although the dominant pattern in the southern Appalachian Mountains was the conversion of other cover types to FOR, an important secondary pattern involved the conversion of TRN and WTR to AGR. The shift from TRN occurred at midslopes, whereas the shift from WTR to AGR occurred in valleys (Tables 2, 3). The conversion of TRN to AGR contrasted with other studies that identified agricultural and residential areas as more likely to become fragmented by transportation systems (Hawbaker et al 2004). Perhaps one of the reasons our study

FIGURE 1 Repeat photographs from Walker’s Creek near White Gate, Virginia. The top photograph was taken in 1880 and the bottom photograph in 2008. The hill in the background represents the conversion of higher elevation agricultural lands to forest. (Top photo by J.C. Porter; bottom photo by L.E. Hendrick)

FIGURE 2 Repeat photographs from Craig's Creek in Craig County, Virginia. The top photograph was taken in 1880 and the bottom photograph in 2008. The road in the foreground represents the conversion of agricultural land to transportation systems. (Top photo by J.C. Porter; bottom photo by L.E. Hendrick)

FIGURE 3 Repeat photographs from Saltville, Virginia. The top photograph was taken in 1880 and the bottom photograph in 2007. This pair of photographs represents the decrease in importance of railroads across the landscape in the southern Appalachian Mountains. (Top photo by J.C. Porter; bottom photo by L.E. Hendrick)

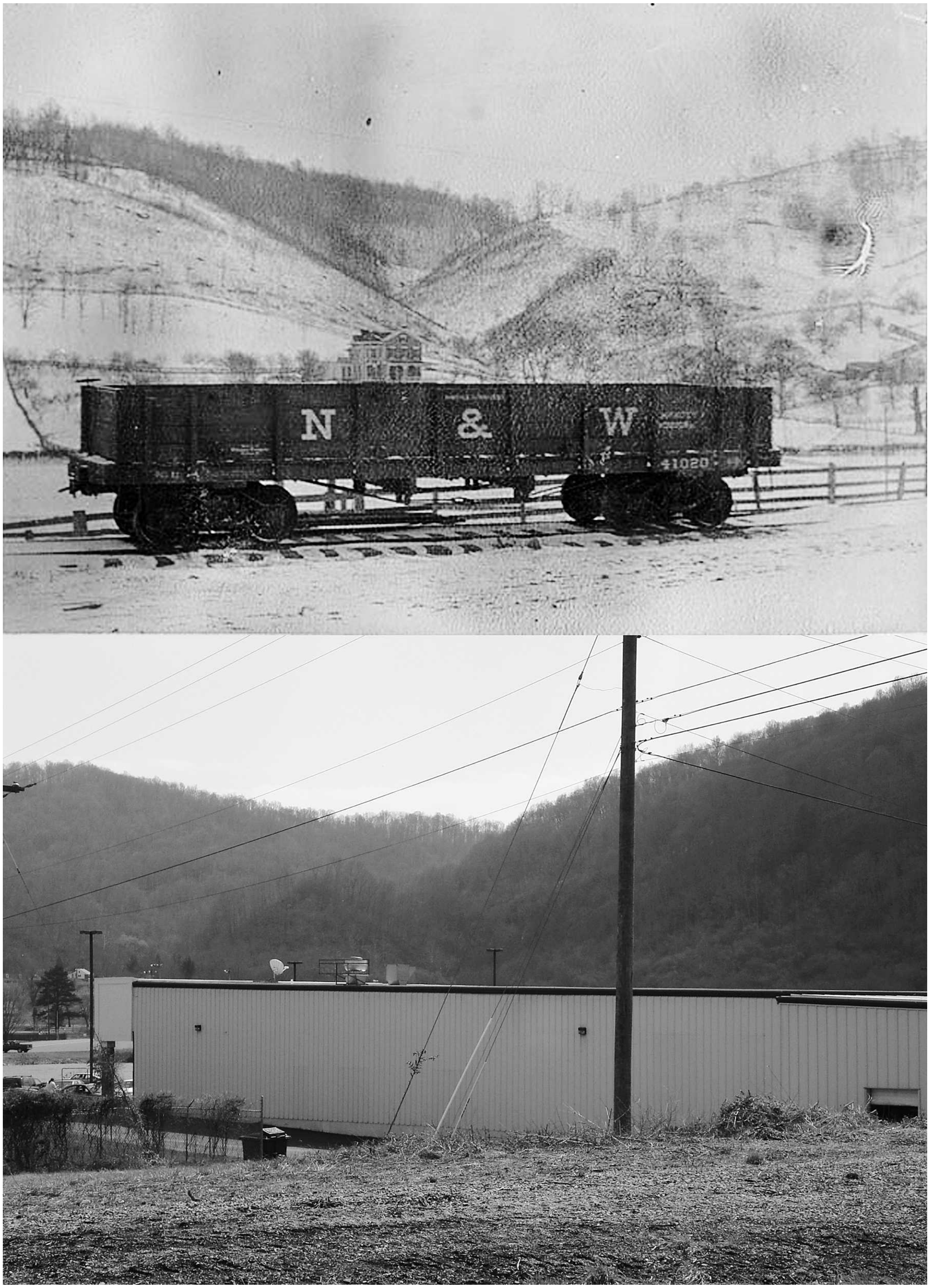

TABLE 3 Cover class changes were compared across 3 topographical positions (ridge, midslope, and valley). The chi-squared (χ^2) values and *P* values shown represent the test for whether cover class changes between the 2 time periods varied by topographical positions. Only those with significant changes by topographical position are shown, and the values in the columns below the topographical positions list the number of pixels of each cover class by topographical position and the percent change across the 2 time periods. The cover classes are abbreviated as AGR (agriculture), FOR (forest), RES (residential or commercial), ROC (rock), and TRN (transportation system).

Cover classes	Year/% change	Topographical positions		
		Ridge	Midslope	Valley
AGR	1880	15,078	1,657,957	1,733,643
***P* = 0.00**	2008	0	1,044,513	1,677,902
χ^2 = 79,839	*% change*	−100.0%	−37.0%	−3.2%
FOR	1880	1,576,162	888,333	49,879
***P* = 0.00**	2008	1,721,570	1,870,759	585,449
χ^2 = 420,203	*% change*	+9.2%	+52.5%	1073.7%
RES	1880	0	1,004,011	911,535
***P* = 0.00**	2008	0	929,845	682,213
χ^2 = 9803	*% change*	0.0%	−7.4%	−25.2%
TRN	1880	0	219,557	462,298
***P* = 0.00**	2008	0	223,812	450,742
χ^2 = 148	*% change*	0.0%	+1.9%	−2.5%

area experienced a conversion of TRN to AGR was the decline in the importance of railroads in the southern Appalachian Mountains (Lewis 1998). The conversion of WTR to AGR was likely a reflection of the loss of importance of hydropower (Copenheaver et al 2007). The initial photographic collection contained many photographs of mills and their associated mill ponds, but as water power became a less important source of energy these mill ponds were drained and the land was converted to agriculture.

This study provided information about past and current landscape conditions in the southern Appalachian Mountains; however, the photographs from 2008 do not reflect a "final stage." Other areas that experienced similar shifts from agriculture to forest later experienced a shift toward residential property; perhaps this may be a future pattern for this region as well (Matlack 1997).

Conclusion

Human settlement and land use in the southern Appalachian Mountains was highly governed by topography. Through the application of repeat photography, we were able to quantitatively document the land use changes in this region from 1880 to 2008. Because of political, military, and economic drivers, the mountain region saw 19% of its agricultural land converted to forest and 18% of its residential and commercial land converted to forest. This new landscape represents a major shift both in ecology and in landownership because much of the newly established forest lies within the boundary of the Washington-Jefferson National Forest.

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